University of Hawaii
Institute for Astronomy
Honolulu, Hawaii 96822

This report covers the period from 1 October 1999 through 30 September 2000, and was compiled in October 2000.

1 Introduction

The Institute for Astronomy (IfA) is the astronomical research organization of the University of Hawaii (UH). Its headquarters is located in Honolulu on the island of Oahu near the University of Hawaii at Manoa, the main UH campus. The IfA is responsible for administering and maintaining the infrastructure for Haleakala Observatories on the island of Maui and for Mauna Kea Observatories (MKO) on the island of Hawaii.

More information is available at the Institute's World Wide Web site: http://www.ifa.hawaii.edu/.

2 Staff

The scientific staff during this report period consisted of Joshua E. Barnes, Ann M. Boesgaard, Wolfgang Brandner, Douglas Burke, Kenneth C. Chambers, Antoinette Songaila Cowie, Lennox L. Cowie, Harald Ebeling, Isabella M. Gioia, J. Elon Graves, Donald N. B. Hall, James N. Heasley, J. Patrick Henry, George H. Herbig, Klaus-Werner Hodapp, Esther M. Hu, David C. Jewitt, Robert D. Joseph, Nick Kaiser, Richard Knabb, John Kormendy, Jeffrey R. Kuhn, Barry J. LaBonte, Jing Li, Haosheng Lin, Gerard A. Luppino, Eugene A. Magnier, Eduardo L. Martín, Robert A. McLaren (Interim Director), Karen J. Meech, Donald L. Mickey, Malcolm J. Northcott, Tobias C. Owen, Andrew J. Pickles, Narayan S. Raja, John T. Rayner, Pui Hin W. Rhoads, A. Kathleen Robertson, Claude Roddier, François J. H. Roddier, David B. Sanders, Theodore Simon, Alan Stockton, David J. Tholen, Alan T. Tokunaga, John L. Tonry, R. Brent Tully, William D. Vacca, Richard J. Wainscoat, and Gareth Wynn-Williams.

Postdoctoral fellows included Hervé Aussel (James Clerk Maxwell Fellow), Amy Barger (Hubble fellow), Pierre Baudoz, Nicholas Biver (James Clerk Maxwell Fellow until 30 June 2000), Yanga R. Fernandez, Renate Kupke, Jana Pittichova (NATO-NSF Postdoctoral Fellow), and Gillian Wilson (Parrent Fellow).

The following students completed the requirements for a Ph.D.: Gabriela Canalizo, Håkon Dahle, James Deane, Alex Stephens, Chadwick Trujillo, and Robert Whiteley.

The other graduate students during the report period were James Armstrong, Elizabeth Barrett, Brian Barris, James Bauer, George Bendo, Peter Capak, Michael Connelley, Michael Cushing, Scott Dahm, David Donovan, Eliza Fulton, Cyrus Hall, Catherine Ishida, Kevin Jim, Dale Kocevski, Christopher Mullis, Michael Nassir, Megan Novicki, Daniel Potter, Barry Rothberg, Robert Thornton, Scott Sheppard, and Wei-Hao Wang.

Visiting colleagues included Marcelo Emilio, Miwa Goto, Olivier Guyon, Masatoshi Imanishi, Roland Meier, Bérengère Parise, and Bradford Smith.

2.1 New Faculty

In June 2000, the University of Hawaii Board of Regents appointed Rolf-Peter Kudritzki director of the IfA beginning in October 2000. At the time of his appointment, he was professor of astronomy and director of the Institut für Astronomie und Astrophysik (University Observatory) at the University of Munich.

Haosheng Lin was appointed to an assistant astronomer position. He has considerable expertise in instrumentation for solar astronomy, and he plans to continue his work on infrared measurements of solar magnetic fields and precise measurements of the solar cycle. He came to the IfA from the National Solar Observatory/Sacramento Peak in Sunspot, New Mexico, where he held the position of assistant astronomer. He is based in Waiakoa on Maui and is also working at the Mees Solar Observatory on Haleakala.

Eduardo Martín was appointed to an assistant astronomer position. His areas of research are brown dwarfs and low-mass stars. He joined the IfA after completing a postdoctoral fellowship at the California Institute of Technology.

Szapudi was appointed to an assistant astronomer position. A cosmologist, he comes to the IfA from the Canadian Institute of Theoretical Physics at the University of Toronto, Canada, where he has held the position of senior research associate. He is expected to arrive at the IfA in January 2001.

2.2 Honors and Awards Received

Sanders won the Humbolt Research Award for Senior US Scientists. F. Roddier won the UH Board of Regents' Medal for Excellence in Research for his work in adaptive optics. Chambers won the UH Board of Regents' Medal for Excellence in Teaching.

3 Mauna Kea Observatories

The telescopes in operation during the report period were the UH 2.2 m and 0.6 m telescopes; the 3 m NASA Infrared Telescope Facility (IRTF), operated by the UH under a contract with NASA; the 3.6 m Canada-France-Hawaii Telescope (CFHT), operated by the Canada-France-Hawaii Telescope Corporation on behalf of the National Research Council of Canada, the Centre National de la Recherche Scientifique of France, and UH; the 3.8 m United Kingdom Infrared Telescope (UKIRT), operated in Hawaii by the Joint Astronomy Centre (JAC) based in Hilo on behalf of the Particle Physics and Astronomy Research Council of the United Kingdom; the 15 m James Clerk Maxwell Telescope (JCMT), a submillimeter telescope operated by the JAC on behalf of the United

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Supplementary Notes

Abstract
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Kingdom, Canada, and the Netherlands; the 10.4 m Caltech Submillimeter Observatory (CSO), operated by the California Institute of Technology for the National Science Foundation (NSF); the Hawaii antenna of the Very Long Baseline Array (VLBA), operated by the National Radio Astronomy Observatory (NRAO); the 10 m Keck I and Keck II telescopes of the W. M. Keck Observatory, which is operated by the California Association for Research in Astronomy for the use of astronomers from the California Institute of Technology, the University of California system, NASA, and UH; the 8.3 m Subaru Telescope, operated by the National Astronomical Observatory of Japan (NAOJ); and the 8.1 m Gemini North Telescope, built by an international partnership and managed by the Association of Universities for Research in Astronomy.

Construction continued on the Submillimeter Array (SMA), a collaborative project of the Smithsonian Astrophysical Observatory and the Institute of Astronomy and Astrophysics of the Academia Sinica of Taiwan.

3.1 Mauna Kea Master Plan

In June, the UH Board of Regents approved a new Master Plan for the UH-managed lands on Mauna Kea. The new plan provides guidelines for astronomy development for the next 20 years and introduces a new management structure.

All future development will be located within a 525 acre (213 hectare) Astronomy Precinct, leaving the surrounding 10,760 acres (4,358 hectares) as a natural and cultural preserve. The guidelines prohibit development on currently undisturbed cinder cones and require facility designers to minimize environmental impact, including visual impact. Projects foreseen through the year 2020 are (1) a next generation optical/IR telescope in the 25–50 m range, (2) renovation or replacement of up to five of the older existing facilities, (3) expansion of the W. M. Keck Observatory with the addition of four to six 1.8 m outrigger telescopes, (4) expansion of the Submillimeter Array with the addition of up to 12 more antennas (for a total of 24), (5) one new telescope in the 4–12 m range at a currently unused site, and (6) a 1 m instructional telescope.

The plan establishes a new Office of Mauna Kea Management, located at the University of Hawaii at Hilo. The office will have a director reporting to the UH Hilo chancellor, support staff, and a team of guides who will work on the mountain. Also included in the plan is a Mauna Kea Management Board representing the various stakeholder constituencies. This seven-person board will have an oversight role for all activities on Mauna Kea. It will serve as the interface between the UH and the community, and it will provide policy guidance to the Management Office. Finally, the plan calls for a panel of Hawaiian elders, the Kahu Kupuna Council, to provide policy recommendations and advice on Hawaiian cultural matters.

The new Master Plan is the product of two years of hard work by a great many people. There is much more work to be done in the implementation phase. With this plan as a framework, and with a continued spirit of cooperation, it will be possible to balance the interests of all for whom Mauna Kea is so precious.

3.2 IfA Hilo Facility and Infrastructure

The 35,000 square foot (3300 m^2) IfA Hilo Facility, completed during the summer, provides a state-of-the-art operations base for the IfA's activities on Mauna Kea, plus long-awaited expansion space for our research, instrumentation, teaching, and outreach programs. The facility is equipped with a high-bandwidth fiber-optics link to the other base facilities in the UH Hilo University Park and to the telescopes on Mauna Kea for remote observing. Our Hilo-based staff (about 30 people) moved into the new building during August and September.

The MKO connection to the Internet has been upgraded to DS-3 capacity (45 Mbits s^{-1}) with funding provided by the NSF. The local area network linking the observatories to each other and to the base facilities has been converted to asynchronous transfer mode (ATM) technology.

4 HALEAKALA OBSERVATORIES

The administrative staff consisted of M. Maberry, D. O'Gara, K. Rhoden, K. Kimura, and J. Perreira, and the technical staff included E. Olson, M. Waterson, R. Coulter, G. Nitta, J. Frey, C. Foreman, L. Hieda, B. Lindsey, K. Ventura, and J. Kamibayashi.

4.1 Mees Solar Observatory

Mees Solar Observatory supports IfA solar scientists in data acquisition by running diverse observational programs with its telescope cluster. The observatory regularly co-observes with the satellites *Yohkoh*, *Solar and Heliospheric Observatory* (*SOHO*), and *Transition Region and Coronal Explorer* (*TRACE*), and also participates in special satellite and ground-based observatory campaigns. One of the unique observational capabilities at Mees is the ability to perform measurements of the temporal evolution of photospheric vector magnetic fields. The observatory's complement of instruments includes the Imaging Vector Magnetograph (IVM), Haleakala Stokes Polarimeter, Mees CCD Imaging Spectrograph (MCCD), Mees White Light Telescope, and Coronal Limb Imagers.

Active instrumentation projects include adding rapid wavelength selection to the IVM to permit sequential photospheric and chromospheric magnetic observations, and a new CCD camera and data system for the MCCD for high-speed spectral imaging in collaboration with the upcoming *High Energy Solar Spectroscopic Imager* (*HESSI*), a Small Explorer Progam (SMEX) mission.

4.2 LURE Observatory

LURE is a satellite laser ranging (SLR) observatory. LURE utilizes a high-powered pulsed laser to obtain distance measurements to satellites in Earth orbit. LURE is funded by the Space Geodesy Networks and Sensor Calibration Office of NASA Goddard Space Flight Center. The missions of the target satellites include monitoring of Earth resources and climate parameters, measurements of ocean levels and temperatures, plate tectonics, the improvement of the Global Positioning System (GPS), as well as special missions related to the physics of tethered satellite systems. LURE provides

range data to NASA 7 days a week, and improvements to the computer system and to the operational procedures will soon allow LURE to operate on a 24 hour schedule.

4.3 AEOS-Haleakala Atmospheric Characterization Project

Haleakala Observatories is under contract to the Air Force Research Laboratories to conduct a research program known as the AEOS-Haleakala Atmospheric Characterization (AHAC). This program supports the U.S. Air Force Advanced Electro-Optical System (AEOS) Telescope on Haleakala by providing comprehensive atmospheric characterization and timely prediction of inclement weather conditions at the observatory site. The instrument suite that supports these site measurements includes a daytime/nighttime optical seeing monitor and a network of remote meteorological systems linked by radio modems. The optical seeing monitor captures star image data at high frame rates and uses a differential image motion technique to allow the computation of seeing statistics over intervals of a few seconds. Data from the remote meteorology stations are processed using an artificial intelligence program to generate locally specific predictions of adverse weather events on a time horizon of 30 min.

4.4 MAGNUM Telescope Project

The 2 m Multi-color Active Galactic Nuclei Monitoring (MAGNUM) Telescope is dedicated to studying the variation of light from active galactic nuclei (AGNs). The project is a collaboration between the University of Tokyo and the University of Hawaii. The main scientific objective of MAGNUM is to measure distances to AGNs and quasars up to $z = 1$. The telescope is designed to be operated remotely and to conduct observations autonomously. The main scientific instrument is a two-detector camera that can obtain images from 0.3 to 3.4 μm. The telescope is in the final phase of commissioning.

4.5 Faulkes Telescope

On 26 June 1999, the UH-IfA and the Faulkes Telescope Corporation signed a Memorandum of Understanding to locate a 2 m telescope at Haleakala Observatories. This professional-grade telescope will be the largest in the world dedicated to astronomical education. Access to the telescope in Hawaii will be available to public and private schools and to the science programs of the UH system and other colleges and universities.

The telescope's construction will be financed by the Dill Faulkes Educational Trust of the United Kingdom and will be named in honor of Dr. Martin "Dill" Faulkes, the founder of the trust. Plans call for having the instrument operational in 2002. The telescope will be housed in a state-of-the-art facility with an enclosure that will open like a clamshell and that will be capable of exposing the entire telescope to the night sky.

The Faulkes Telescope will be the third in a series of 2 m telescopes being constructed by Telescope Technologies Limited in Birkenhead, Merseyside, in northwest England. The design heritage of these telescopes comes from that of the William Herschel telescope. The first of these instruments will be the Liverpool Telescope, scheduled to become operational in the Canary Islands in October 2000.

The initial instrument on the Faulkes Telescope will be a state-of-the-art CCD camera. The IfA plans to add an infrared camera to the instrument complement shortly after the telescope is commissioned. This will allow for daytime observations by schools in Hawaii. The control system will allow observations to be made both interactively over the Internet or by queued robotic operation.

The Faulkes Telescope Project will draw upon the great public interest in astronomy to teach students what science is. Astronomers in Hawaii and the United Kingdom plan to engage students in research projects that will be published in the scientific literature. They will encourage joint projects in which students will collaborate over the Internet with their counterparts halfway around the world.

4.6 Solar-C

The Solar-C instrument is a 0.5 m off-axis coronagraphic reflecting telescope being built on Haleakala adjacent to the Mees Solar Observatory. This instrument will (1) allow coronal observations that have not been realized, even from space, (2) develop technology that IfA scientists believe will be used for future satellite observations, and (3) support several long-term coronal observing platforms that extend intermittent coronal space observations. Unlike most telescopes, light strikes the Solar-C mirrors off-axis, at an angle to their surfaces. No light is blocked, reflected, scattered, or diffracted by the mirrors or their support structure aside from the superpolished optical surfaces.

The mechanical components of the Solar-C instrument have been fabricated. The off-axis secondary mirror is completed, and as of fall 2000 the project awaits final polish of the primary mirror.

5 Instrumentation

5.1 Adaptive Optics

The UH 36-element curvature sensing adaptive optics system, Hōkūpa'a, had its second commissioning run at the Gemini North Telescope in March 2000; Hōkūpa'a utilizes the UH near-infrared camera, QUIRC. In June 2000, the optical design was modified to allow dithering, and a new lenslet array with a larger field of view ($4''$) was installed. Also, as a part of UH graduate student D. Potter's thesis, a Wollaston prism for high-contrast detection of polarized emission was implemented on Hōkūpa'a. Two observing runs in June/July and July/August that were part of the Gemini Demonstration Science program observed the Galactic center. The Gemini QuickStart science observations with Hōkūpa'a began in September 2000. A total of six science runs with Hōkūpa'a at Gemini were scheduled for the year 2000 ($\sim$5–12 nights/month after July).

Observations in the first half of 2000 were hampered by the worse-than-average weather conditions in the Pacific basin due to the fading La Niña phenomenon. Nightly problems with telescope operations, as well as various problems with Hōkūpa'a, significantly cut into the time spent observing when the weather was favorable. In September, the average

seeing conditions improved, and Hōkūpaʻa consistently produced image cores with full width at half-maximum, close to the diffraction limit of an 8 m telescope in the K and H bands with Strehl ratios of $\sim$30%.

Hōkūpaʻa is capable of using sources as faint as V = 15 mag to 17 mag (depending on source color) and up to 45″ off-axis from the science target for wavefront sensing. The larger field of view of Hōkūpaʻa's lenslet array (4″) enables the use of extended objects (e.g., Neptune or the core of M32) for this purpose. For direct imaging, Hōkūpaʻa is currently capable of detecting point sources 6 mag fainter and separated by 0.″3 from a bright object. For more information on the performance of Hōkūpaʻa, consult the Web page, http://www.gemini.edu/sciops/instruments/uhaos.

5.2 The Gemini Near-Infrared Imager (NIRI)

NIRI, built at IfA, will be the main infrared imaging instrument on Gemini North. Its first task will be the commissioning of the telescope and a characterization of its performance.

NIRI provides three pixel scales for scientific observations, the finest (0.02 arcsec pixel^{-1}) has been chosen to sample properly the expected image quality delivered by the adaptive optics system; the middle one (0.05 arcsec pixel^{-1}) is best matched to the image quality expected from tip-tilt corrected images on the best nights; and the widest field (0.12 arcsec pixel^{-1}) fills almost the whole unvignetted science field of the telescope. The science detector array is a 1024 × 1024 Aladdin array with 27 μm pixels. Besides basic imaging, NIRI provides the capability for grism spectroscopy at low to moderate spectral resolutions (600 and 2000 for J, H, and K, and 1500 for L). NIRI will also allow coronagraphic observations and is equipped with a Wollaston prism for polarimetric work.

NIRI is using an internal on-instrument wavefront sensor (OIWFS) to keep differential flexure between the science channel and the OIWFS within acceptable limits. Optical wavefront sensors perform well almost everywhere in the sky, but an important class of scientific projects, studies of deeply embedded very young stars in nearby molecular clouds, is not able to utilize such a system. For this reason, and in light of advances in the noise performance of near-infrared detector arrays, the NIRI OIWFS uses a HAWAII 1024 × 1024 HgCdTe array to allow guiding in obscured regions of the sky and during twilight.

In the report period, NIRI was completed and went through the preshipment acceptance testing. It was shipped to the Gemini Hilo base facility in May 2000 and subsequently tested there. A first test run at the telescope in August 2000 was successful, and NIRI is currently being fine tuned in preparation for commissioning.

5.3 Infrared Camera and Spectrograph (IRCS) for the Subaru Telescope

The IRCS, another IfA product, is a facility instrument for the Subaru Telescope on Mauna Kea. It is now being commissioned at the telescope under the direction of Project Scientist and current PI N. Kobayashi (NAOJ). It incorporates a 1024 × 1024 Aladdin 2 array that is sensitive from 0.9 to 5.6 μm. IRCS has been designed to deliver diffraction-limited images from 2 to 5 μm and to provide spectroscopy with grisms and a cross-dispersed echelle. The camera can also be used as a slit viewer.

Tokunaga previously served as the PI for this project. Co-investigators Hodapp and Rayner, and Y. Kobayashi, T. Maihara, and T. Nagata (NAOJ) have worked with Tokunaga and Kobayashi on this project.

5.4 SpeX

SpeX, a new medium-resolution 0.8–5.5 μm spectrograph and imager for the NASA IRTF, was successfully commissioned during June and July 2000. Since September the instrument has been working smoothly during observing time awarded by the Telescope Application Committee. Over 40% of observing time during the fall 2000 semester was awarded to programs using SpeX. The instrument was funded primarily by NSF with additional funding from NASA for the detector arrays.

The spectrograph uses gratings and prism cross-dispersers to provide spectral resolving powers (R) of up to 2500 simultaneously across 0.8–2.45 μm, 1.9–4.2 μm, or 2.3–5.5 μm. A low-resolution prism mode covering 0.8–2.5 μm (R up to 250) and single-order long-slit modes (R up to 2500) are also available. An Aladdin 3 1024 × 1024 InSb array is used in the spectrograph. The infrared imager/slit-viewer uses an Aladdin 2 512 × 512 InSb and covers a 60″ × 60″ field. Infrared guiding is done on objects in the field or on spillover from the science object in the slit. The imager also contains a full complement of science imaging filters.

SpeX was designed and built by IRTF/UH staff: Rayner (PI), G. Ching (instrument technician), A. Denault (software engineer), P. Onaka (electrical engineer), W. Stahlberger (mechanical engineer), D. Toomey (project engineer), and D. Watanabe (instrument technician). Support astronomer Vacca and graduate student Cushing are writing the IDL-based automatic spectral extraction program, SpeXtool. At the telescope SpeX is maintained by the IRTF day crew, and user support is provided by IRTF support astronomers.

For details about applying to IRTF and using SpeX, visit the IRTF Web site at http://irtf.ifa.hawaii.edu/.

5.5 AEOS Spectrograph

This high-resolution spectrograph being constructed for the U.S. Air Force Advanced Electro-Optical System (AEOS) Telescope is nearing completion. Installation of the dual-arm visible and near-infrared instrument into one of the AEOS coudé rooms is about to begin. Due to the large size of this instrument, integration and testing will take place at the facility.

The spectrograph will employ large-format array detectors to provide resolving power of up to 50,000 together with wide spectral coverage over the 0.5–2.5 μm wavelength range. The visible arm will utilize a 4K × 4K CCD mosaic being developed by Luppino. The infrared arm will utilize a 2K × 2K HgCdTe hybrid array being developed by Rockwell Science Center. Science-grade devices of both types have been delivered and are undergoing characterization.

Fabrication of all common optical assemblies and com-

ponents for the visible arm has been completed, and the system will be installed and tested during late 2000. Completion of mechanical detailing and fabrication of IR subsystem components is proceeding in parallel. Assembly and testing of the IR arm and integration of the two spectrograph arms will be completed by July 2001.

Institute personnel responsible for this project are Mickey (PI), Stockton, Hodapp, and Luppino.

6 Galactic and Extragalactic Studies

Barger and Cowie have been working with collaborators R. Mushotzky and K. Arnaud (NASA Goddard), and E. Richards (Univ. Alabama) on identifying the hard X-ray sources responsible for the extragalactic hard X-ray background. The *Chandra* satellite was used to resolve most of the background in the Hawaii field SSA13, and follow-up studies have shown that the galaxies containing the AGNs producing the X-ray sources are distributed over a wide range in redshift. Barger is now working with collaborators at Penn State on the ultradeep *Chandra* image of the Hubble Deep Field region and with collaborators at MIT and Cambridge on studies of sources lying behind modest redshift lensing clusters A370 and A2390.

Songaila, Hu, L. Cowie, and R. McMahon (IoA, Univ. Cambridge) studied limits on the absorption due to neutral hydrogen clouds of the Lyman-α forest in the $z = 5$ quasar J033829.31+002156.3. This Gunn-Peterson test constrains the amount of neutral hydrogen that can be present at high redshifts based on spectroscopic studies of absorption of the quasar's continuum light below the redshifted Lyman break. High-resolution spectra obtained with the Keck HIRES spectrograph were compared and calibrated against lower-resolution spectrophotometrically calibrated spectra obtained with the Keck LRIS spectrograph. Portions of the HIRES spectra return to near the extrapolated quasar continuum, yielding an upper limit of $\tau = 0.1$ on the regions of minimum opacity. This suggests a high metagalactic ionizing background ($J_\nu \gg 4 \times 10^{-23}$ erg cm^{-2} s^{-1} Hz^{-1} sr^{-1} at $z \sim 4.72$) for the early universe for even minimum consistency with nucleosynthesis measurements of baryon density, even if the opacity arises in underdense regions of the intergalactic gas.

Dahle completed his thesis with supervisor Kaiser. He studied a large, complete X-ray–selected sample of clusters and obtained weak gravitational lensing mass maps for roughly 30 clusters. This represents a substantial increase in the total amount of weak lensing information obtained so far. Some 8 or so of these were observed with the UH8K camera and give mass profiles out to a large radius. Essentially all of the clusters were detected significantly. The mass and X-ray properties were compared and show a strong scatter in mass at a given X-ray luminosity. A composite cluster mass profile was computed and compared to the profile of the luminous matter.

After the completion of the optical identification of the sources in the deepest region of the *ROSAT* All-Sky Survey, the so-called North Ecliptic Pole (NEP) region, Gioia, Henry, and Mullis have compiled a well-defined and complete sample of X-ray clusters. The sample is being used to investigate the nature of cluster evolution and explore potential implications for large-scale structure. Four papers were finalized for submission to *The Astrophysical Journal Letters*. These papers give an overview of the survey and of the X-ray data. They also present evidence for a deficit of $z > 0.3$ clusters with respect to the local universe and the existence of a supercluster at $z = 0.087$ consisting of at least 21 clusters and groups. Follow-up observations for one of the most distant NEP clusters at $z = 0.81$ with the *X-ray Multi-Mirror Mission* satellite have been awarded.

Gioia is collaborating with M. Donahue (STScI) and other colleagues on *Chandra* observations of MS0451-03, the brightest cluster at $z > 0.5$ in the Einstein Extended Medium Sensitivity Survey. These data combined with other multiwavelength datasets will allow them to probe the density structure of gas in a cluster at high redshift.

Gioia has an ongoing collaboration with T. Maccacaro and A. Wolter (Observ. Brera, Milan) and A. Caccianiga (Observ. Lisbon) to search for radio–X-ray-selected BL Lac objects. The sample they are building already consists of about 70 BL Lacs and will be instrumental in assessing the evolutionary behavior of BL Lac objects on a robust statistical basis. They also plan to study the connection between BL Lac objects and other flat spectrum radio quasars that share with BL Lacs many of their observed properties, such as variability or relativistic effects but not the optical properties (i.e., the presence of strong emission lines).

Hu, Cowie, and McMahon continue studies of very high redshift galaxies. They are using a combination of deep narrowband filter imaging at the Keck telescope in long-wavelength atmospheric windows around redshift $z \sim 5.7$ and $z \sim 6.5$ to select objects via their redshifted Lyα emission line along with deep multicolor imaging. This technique has proved to be a robust and successful method of identifying the highest redshift galaxies now known, with the hydrogen Lyα emission linewidth amplified by the object's redshift. It shows distant galaxies in the light of their early star-forming activity by the enhanced contrast in the line emission to the neighboring continuum starlight. Recent work has focused on extending the samples at redshifts $\gtrsim$5. Using observations in gravitationally lensed clusters, the first identifications of $z \sim 6.5$ galaxies have been made. High-resolution spectroscopy performed with the LRIS at Keck show the emission line is too narrow to be due to O II emission from low-redshift, foreground galaxies, and there is no detected flux in the deep Keck and archival *HST* images at visible wavelengths below 8200 Å, where intervening neutral hydrogen clouds of the Lyman alpha forest absorb light below the redshifted Lyman break. Deep multicolor studies show that the brightest $z > 5$ objects can be selected with a color break criterion using the optical R and Z (∼9200 Å) bands, but that more typical high-z galaxies will be marginally below current Z magnitude limits (∼25.3 AB mag).

Using the Cooled Infrared Spectrograph and Camera (CISCO) on the Subaru Telescope, Hu started a program of deep infrared imaging of the brightest $z > 5$ galaxies with T. Maihara and F. Iwamura (Univ. Kyoto), and K. Motohara (NAOJ). The bright $z \sim 5.74$ galaxy, SSA22-HCM1, shows a flat (F_ν) spectrum out to 2.1 μm (∼3200 Å in the rest frame),

and is consistent with minimal or no dust extinction. Star formation estimates based on ultraviolet continuum light are therefore consistent with the earlier estimates based on optical emission-line and Z-band (~9200 Å) continuum estimates.

Kaiser, Wilson, and Luppino presented estimates of the gravitational lensing shear variance obtained from images taken at the CFHT using the UH8K CCD Mosaic Camera. Six fields were observed for a total of 1 hr each in V and I, resulting in catalogs containing approximately 20,000 galaxies per field with properly calibrated and optimally weighted shear estimates. These were averaged in cells of sizes ranging from 1′.875 to 30′ to obtain estimates of the cosmic shear variance $\langle\overline{\gamma}^2\rangle$, with uncertainty estimated from the scatter among the estimates for the 6 fields. At scales $\lesssim 10'$ the results were found to be in good agreement with those of other groups and with currently fashionable cosmological models. At larger scales the shear variance falls below the theoretical predictions, with a null detection of shear variance averaged in 30′ cells of $\langle\overline{\gamma}^2\rangle = (0.28 \pm 1.84) \times 10^{-5}$.

Tully continued work on the extragalactic distance scale and studies of the peculiar velocity field of the Local Supercluster. Improvements in the luminosity–rotation rate method of distance determinations have resulted from (1) better determination of inclination corrections, (2) the acquisition of far larger and more complete calibration samples, and (3) many new zero-point calibrators from the *HST* cepheid programs. Tully and M. Pierce (Indiana Univ.) now find $H_0 = 77 \pm 8$ km s^{-1} Mpc^{-1} (95% statistical certainty). Errors are now dominated by potential systematic effects.

Tully is also collaborating with W. Saunders (AAO), B. Mobasher (STScI), and others on an observing program to acquire I and K' photometry and linewidths on a sample of 1300 galaxies selected with all-sky uniformity from an *IRAS* redshift survey. *IRAS* selection and K' photometry assures more even coverage of the sky than provided by previous studies. H I observations are continuing, but the optical and infrared observations are completed. In a companion program, K' imaging and spectroscopic follow up have made the *IRAS Point Source Catalogue: Redshift Survey* complete to very low galactic latitudes.

Tully collaborates with E. J. Shaya (Raytheon), and P. J. E. Peebles and S. Phelps (Princeton) on a least-action reconstruction of the orbits of galaxies in the Local Supercluster, in order to understand the peculiar velocity field. Their recent focus has been on the nearby field, developing models that simultaneously take uncertainties in distance and redshift into account, and that explore the great improvements possible if measurements of proper motions become available.

Tully is also working with N. Trentham (Cambridge Univ.) and M. Verheijen (NRAO) in an attempt to quantify constraints on the faint end of the galaxy luminosity function. It is becoming increasingly clear that the luminosity function is flat or even falling toward faint luminosities in moderate-to low-density environments. They speculate that the galaxy formation processes were effectively quenched in low-mass halos after the epoch of reheating of the universe by early star formation or QSOs.

Wilson, Kaiser, Luppino, and L. Cowie presented measurements of the extended dark halo profiles of bright early-type galaxies at redshifts $0.1 < z < 0.9$ obtained via galaxy-galaxy lensing analysis of images taken at the CFHT using the UH8K CCD Mosaic Camera. They used $V - I$ color and I magnitude to select bright early-type galaxies as the lens galaxies, yielding a sample of massive lenses with fairly well determined redshifts. They paired these with faint galaxies lying at angular distances $20'' < \theta < 60''$, corresponding to physical radii of $26 < r < 77$ h^{-1} kpc ($z = 0.1$) and $105 < r < 315$ h^{-1} kpc ($z = 0.9$), and computed the mean tangential shear $\gamma_T(\theta)$ of the faint galaxies. The shear signal was detected at a high level of significance, and gives a value for the average mean rotation velocity of an $L_\star$ galaxy halo at $r \sim 50$–200 h^{-1} kpc of $v_\star = 238^{+27}_{-30}$ km s^{-1}. Subdividing the sample showed little evidence for evolution with redshift. These halo masses are somewhat lower than a simple perfectly flat rotation curve extrapolation from smaller-scale dynamical measurements, and are considerably lower than the masses found for the best-studied X-ray halos. They do however agree extremely well with the masses of halos of the same abundance in ΛCDM simulations.

7 Star Formation and Interstellar Matter

In 1996 Herbig published (AJ, 111, 1241) a description of the peculiar reflection nebula IC 349 (Barnard's Merope Nebula), which is only 30″ from the bright star 23 Tauri. Herbig and Simon have now obtained new high-resolution *HST*/WFPC2 images of IC 349 in *BVRI*. With 8 times the resolution of the best f/10 frames taken with the UH 2.2 m telescope for the 1996 paper, much interesting new structure appears.

Herbig and Simon have now expanded in more detail the hypothesis that IC 349 is part of an outlying fragment of the Taurus-Auriga dark clouds that the Pleiades cluster has encountered in its southward motion, and that IC 349 as it nears 23 Tau is being shaped by radiation pressure. Several observations support this idea. The color gradient across one side of IC 349 is as expected if the dust is being sifted by differential radiation pressure and, at the same time, being dragged by the H and H_2 gas with which it is mixed. The observed colors can be explained by a mix of silicate and graphite particles with radii between about 0.1 and 1 μm. The proper motion of IC 349 is poorly known, but it is not in conflict with the Tau-Aur hypothesis. The radial velocity has yet to be measured to everyone's satisfaction; an attempt by Deane to detect IC 349 in the millimeter line of ^{12}CO(2–1), which could have settled that vexing question, was unsuccessful.

Herbig and Dahm are essentially finished with their photometry (*BVRI* and *JHK*) and spectroscopy of the young cluster IC 5146 and the adjacent clustering around the Ae/Be star BD+46° 3471. The central star of IC 5146, of type B1 V, illuminates a large emission/reflection nebula in and around which about 80 Hα emission stars brighter than R = 21 have been found. Optical and radio-frequency interstellar lines indicate that a conical cavity is being excavated in the front surface of the background molecular cloud, and it is in the outflowing gas in this cavity that the cluster is located.

Similar clusterings of emission-Hα stars have been found in other young clusters, particularly NGC 1333 and IC 1274.

Dahm has begun photometry and spectroscopy of a number of young clusters of ages between 1 and about 15 Myr to determine how cluster structure and composition evolve with time.

Herbig and Dahm have used that same grism arrangement at the f/10 focus of the UH 2.2 m telescope to investigate the incidence of Hα emission among the brighter members of the cluster NGC 6611 (= M16), which has been reported to contain an unusually high number of Be and Ae stars. The cluster is imbedded in a very bright H II region, so that proper subtraction of the background on slit or multi-object fiber-fed spectra is important. Slitless spectra are not subject to such contamination. Herbig and Dahm examined about 40 suspected Be and Ae stars, and were able to confirm the presence of Hα emission above the continuum level in only 4. However, about 25 much fainter Hα emitters were found in the cluster. These are probably the brightest members of a low-mass T Tauri population. None of these stars are convincingly associated with the famous elephant-trunk structures seen in projection against the H II region.

Herbig published the results of his search for interstellar C_{60} ("buckminsterfullerene") using Keck HIRES spectrograms. The laboratory data leave much to be desired, but what can now be said is that neutral C_{60} could not be detected in any of the heavily reddened OB stars that were examined, notably CygOB2/8A. However, given the relevant ionization potentials, most interstellar C_{60} is probably singly ionized. Two bands at 9577 and 9632 Å are believed to be due to C_{60}^{+}, and are readily detected in CygOB2/8A, a region best observed at Mauna Kea on very dry nights because of heavy atmospheric H_2O structure. Herbig also determined the column densities of CH, CN, and C_2 in that same star, and estimated the amount of interstellar carbon that could be tied up in the diffuse interstellar bands. The conclusion was that neutral C_{60} cannot be a significant sink of interstellar C (less than 0.2–04% of the total amount of C available), but that there could be over 100 times that upper limit in C_{60}^{+}. A similar investigation of the fullerene C_{70} awaits better laboratory information.

Brandner, in collaboration with H. Zinnecker (Astrophysikalisches Institut Potsdam), J. M. Alcala and E. Covino (Osservatorio Astronomico di Capodimonte Napoli), F. Allard (Univ. Lyon), S. Frink and R. Koehler (Univ. California, San Diego), A. Moneti (Institut d'Astrophysique de Paris), M. Kunkel (Astronomisches Institut der Universität Würzburg), and A. Schweitzer (Univ. Georgia), completed the analysis and interpretation of an *HST*/NICMOS survey for substellar companions to weak-line and post–T Tauri stars. The results of the survey suggest that massive substellar companions at separations greater than 30 AU are extremely rare. ISOCAM and ISOPHOT observations of the same targets support the idea that small dust grains get depleted in circumstellar disks on timescales of 10 Myr. This is very likely related to the buildup of larger dust particles and planetesimals.

The study of the Galactic giant H II region NGC 3603 by Brandner and main collaborators E. K. Grebel (Max-Planck-Institut für Astronomie), B. Brandl (Cornell Univ.), and Y.-H. Chu (Univ. Illinois at Urbana-Champaign) was extended. This study is based on data obtained with *HST*/WFPC2 and the Infrared Spectrograph and Array Camera at the Very Large Telescope (VLT) of the European Southern Observatory. The deep infrared observations of NGC 3603 with the VLT confirm that there is no deficit of low-mass stars down to 0.1 $M_{\odot}$, and that the low-mass initial mass function in this starburst cluster is virtually identical with the field IMF in the mass range 0.2–2 $M_{\odot}$. The relative scarcity of stars with intrinsic infrared red excess compared with a less massive star-forming region like Orion suggests that circumstellar disks in starburst environments are transient phenomena and might not survive long enough to form planetary systems.

Sheppard, Brandner, and Tokunaga completed the analysis of near-infrared VLT/ISAAC observations of the circumstellar environment of young stars in southern star-forming regions. Two new edge-on circumstellar disk sources were identified in the Ophiuchus star-forming region. Infrared spectra obtained with the Subaru Telescope and and its CISCO camera show that the bipolar reflection nebulosities above and below the disk planes exhibit featureless continua. The VLT data combined with observations obtained with the *Infrared Space Observatory* nicely confirm theoretical predictions about the effect of disk geometry and inclination angle on the spectral energy distribution of young stellar objects with circumstellar disks.

Brandner, Martín, G. Basri (Univ. California, Berkeley), X. Delfosse (Instituto de Astrofísica de Canarias), and Allard started a *HST*/WFPC2 snapshot program to survey for companions up to 50 free-floating brown dwarfs in the solar neighborhood. The survey studies the binary properties of free-floating brown dwarfs, which should hold important clues to their origin. A second objective is to obtain dynamical mass estimates for the individual companions of brown dwarf binaries.

Magnier has continued work on "transitional" YSOs. His collaborators are R. Waters (Univ. Amsterdam), M. van den Ancker (Center for Astrophysics), and N. McCrady (UC Berkeley). They have recently obtained L', M', and 850 μm photometry of most of the northern objects in their sample. This data completes the measurement of the spectral energy distribution for the objects, and will be combined with the optical spectroscopy obtained previously to study the evolutionary state of these objects. CO (2–1) observations of the sample show that the bulk of the objects, nearly all of which show evidence of optical, ionized outflows, also show molecular outflows. This serves to confirm the transitional state of these objects, on the boundary between the embedded (Class I) and the exposed (Class II) YSOs.

C. Roddier and F. Roddier continued to observe a number of binary T Tauri stars with adaptive optics to estimate their projected orbital velocities and their component variabilities. Results for T Tau were presented at IAU symposium 200, "The Formation of Binary Stars," held in Postdam on 10–15 April 1999.

8 Stellar Astronomy

Boesgaard has been studying the trio of the rare light elements—lithium, beryllium, and boron. These can be destroyed in solar-type stars. Lithium is the most susceptible to

destruction, followed by Be and then B. The large depletion of Li in the mid-F stars in the Hyades and other clusters is now understood to be due to slow-mixing of Li atoms to deep layers, where the temperature is high enough to destroy them. New results on the correlation of Li and Be depletions in field F stars supports this and argues against diffusion, mass loss, and probably, mixing by gravity waves. Rotationally induced mixing is the most probable cause of the Li and Be depletion. The G stars in the Hyades and other clusters have progressively less Li with decreasing surface temperature, whereas the few Be observations in G dwarfs show little or no depletion. Recent results on B show only small depletions in a few stars, and only in those stars with very large deficiencies in Li and Be.

The abundance of beryllium has been determined in unevolved stars over a range metal abundances to enhance the understanding of the chemical evolution of our Galaxy, cosmic-ray theory, and cosmology. Observations of 27 stars have been made with Keck I with HIRES at high spectral resolution (45,000) and high signal-to-noise ratios (60–110 typically). There is a remarkably linear relationship between log N(Be/H) and [Fe/H] with a slope of 0.96 ($\pm$0.04). Similarly, the relationship between log N(Be/H) and [O/H] is linear with a slope of 1.45 ($\pm$0.04). Beryllium increases at the same rate as Fe, but much faster than O. This provides constraints for and insights into models of Galactic chemical evolution. There is some evidence for an intrinsic spread in Be at a given [O/H] or [Fe/H]. There is no evidence of a plateau in Be at the lowest metallicities down to log N(Be/H) = -13.5.

Boesgaard has also been determining chemical abundances in globular cluster turnoff stars with Stephens, J. King (Univ. Nevada, Las Vegas), and C. Deliyannis (Indiana Univ.). Spectroscopic observations at high spectral resolution of unevolved stars in globular clusters have been possible only since the 1993 advent of the Keck I 10 m telescope and its high-resolution spectrometer. They have derived chemical abundances of lithium and several other elements in some unevolved, but identical, stars in three globular clusters. For M13 they have found a spread in Li abundances of a factor of 5 in four very similar stars. For six stars in M92 the range is a factor of 3. The stars with the highest abundances of Li show values that are a factor of 2 above the field halo star Li plateau. The abundances of several other species—Na, Mg, Si, Ca, Ti, Cr, Ni, Fe, Y, and Ba—show no such star-to-star variations. They compared these abundances with those of halo field stars that were derived from Keck HIRES spectra by Stephens for his Ph.D. thesis.

Stephens completed his Ph.D. thesis on possible accretion in the Galactic disk. The Milky Way disk is enveloped in a diffuse, dynamically hot collection of stars and star clusters collectively known as the "stellar halo." Photometric and chemical analyses suggest that these stars are ancient fossils of the galaxy formation epoch, yet little is known about the origin of this trace population. Is this system merely a vestige of the initial burst of star formation within the decoupled proto-Galaxy, or is it the detritus of cannibalized satellite galaxies? In an attempt to unravel the history of the Milky Way's stellar halo, he performed a detailed spectroscopic analysis of 55 metal-poor stars possessing "extreme" kinematic properties. It is thought that stars in orbits that either penetrate the remote halo or exhibit large retrograde velocities could have been associated with assimilated (or "accreted") dwarf galaxies. The hallmark of an accreted halo star is presumed to be a deficiency (compared with normal stars) of the α-elements (O, Mg, Si, Ca, Ti) with respect to iron, a consequence of sporadic bursts of star formation within the diminutive galaxies.

Abundances for a select group of light metals (Li, Na, Mg, Si, Ca, Ti), iron-peak nuclides (Cr, Fe, Ni), and neutron-capture elements (Y, Ba) were calculated using line strengths measured from high-resolution, high signal-to-noise spectral observations collected with the Keck I and the Kitt Peak National Observatory 4 m telescopes. The abundances extracted from the spectra reveal (1) the vast majority of outer halo stars possess supersolar ([α/Fe] > 0.0) ratios; (2) the [α/Fe] ratio appears to decrease with increasing metallicity; (3) the outer halo stars have lower ratios of [α/Fe] than inner halo stars at a given metallicity; (4) at the largest metallicities, there is a large spread in the observed [α/Fe] ratios; (5) [α/Fe] anticorrelates with R_{APO}; and (6) only one star (BD+80 245) exhibits the peculiar abundances expected of an assimilated star. The general conclusion extracted from these data is that the formation of the nascent Milky Way was not dominated by the late accretion of dwarf galaxies *like the ones that currently orbit the Galaxy*. However, the assimilation of fragments early in the evolution of the Galaxy is a natural byproduct of hierarchical models of structure formation and can explain many properties of the halo population.

9 Solar System Studies

9.1 Atmospheres

Owen continued studies of the ice-trapping of volatiles in collaboration with Prof. Akiva Bar-Nun (Univ. Tel Aviv). The goal of these studies is to relate icy planetesimals to ices in the interstellar medium and to the volatiles now found in planetary atmospheres. No isotopic enrichment of deuterium in HDO was detected in laboratory experiments simulating the formation of cometary ices. This result removes one objection to the idea that comets may have preserved interstellar D/H values in their constituent molecules. They also found no fractionation of the xenon isotopes upon incorporation of this gas in ice. This result indicates that the difference between isotopic abundances in atmospheric and solar wind xenon cannot be explained by cometary delivery of this gas to the planets, if this is the only process that could produce the fractionation in comets.

Further analysis of the *Galileo* Probe Mass Spectrometer results by Owen, P. Mahaffy (NASA Goddard), and other members of the instrument team led to the discovery that all the elements measured in the atmosphere of Jupiter (except He and Ne) are enhanced by 3 ± 1 relative to solar abundances ratioed to hydrogen. This is particularly remarkable in the case of argon and nitrogen, as these highly volatile gases would not be expected to show the same enrichment as carbon or sulfur. It appears that the only way to achieve this uniformity is to make the icy planetesimals that delivered these elements at extremely low temperatures, below 30

K. This in turn is a sharp departure from conventional models for the formation of the solar system, which have the icy planetesimals that formed Jupiter condensing out at 150 K. At this temperature, the amount of argon trapped by the ice would be 6 orders of magnitude below the observed value. One is thus led to highly unconventional scenarios for planet formation: The migration of Jupiter from beyond 30 AU, a solar nebula that is as cold as $\sim$25 K at 5 AU, or the early formation of icy planetesimals before or outside the formation of the nebula, in sizes large enough to survive the fall into the nebular disk. The latter possibility carries the attractive advantage that it no longer matters where the giant planet forms (the snowline has no original significance), nor is there any requirement to assume the nearly circular orbits normally expected from formation in the disk.

Owen, Biver, H. E. Matthews (JAC), and A. Marten (Paris Observ., Meudon) detected the 3–2 line of $C^{18}O$ in Titan's submillimeter spectrum with the JCMT. They derived a ratio of $^{18}O/^{16}O$ that is 2.5 times the value on Earth, showing that substantial oxygen escape has occurred on Titan even though there is a steady influx of OH into the satellite's upper atmosphere. Coupled with the earlier detection of a 4.5 times enrichment of $^{14}N/^{15}/N$ and the normality of $^{12}C/^{13}C$, the new result indicates massive atmospheric escape that is buffered by a reservoir of carbon compounds, presumably dominated by CH_4.

9.2 Surfaces

In collaboration with Smith, Owen, and R. J. Terrile (JPL), Meier used observations from NICMOS on the *HST* to produce maps of the surface of Titan at 1.1, 1.6, and 2.0 μm. These maps demonstrated that there are surface features with significant contrast on the trailing side of Titan, ruling out the presence of a hemispherical ocean of hydrocarbons. The contrast of the main bright features is constant with wavelength, so there is no immediate compositional information from these new observations. In particular, they do not support the idea that bright surface features on Titan indicate areas of exposed water ice. No cloud systems were detected on any of the NICMOS images.

J. Luu (Univ. Leiden), Jewitt, and Trujillo used infrared spectrographs on the UKIRT and Keck telescopes to show that water ice has recently appeared on Chiron's surface. The appearance of water ice, identified primarily through its 2 μm absorption, is attributed to the dissipation of the coma surrounding this object. The coma is not due to the sublimation of water ice, which, at about 10 AU heliocentric distance, is far too cold. Instead, the water may be exposed on the surface of Chiron by near-surface activity powered by the sublimation of a more volatile substance, presumably carbon monoxide.

9.3 Asteroids

Under the supervision of Tholen, Whiteley completed his thesis on the properties of near-Earth asteroids. He found that approximately one-third of the observed sample consists of Q-type objects, believed similar to ordinary chondrites and which are rare among main-belt asteroids; another third consists of S-types; and the remainder is distributed among the C, F, and X spectral classes. Another interesting result involves the fast rotation rates for asteroids smaller than about 100 m in diameter. He and Tholen determined rotation periods under 10 min for three more near-Earth asteroids (2000 AG6, 2000 DO8, and 2000 EB14).

Tholen and Whiteley continued to develop and apply techniques for finding near-Earth objects (NEOs) with small aphelion distances. New software for computing short-arc orbits and ephemerides was developed. It facilitated the recovery of an object (1999 XA152) 30 days after it had been seen over only a 6 min interval on one night in December. They found eight other NEOs during the reporting period.

Centaurs are probably the transition objects between the Kuiper Belt objects and the short-period comets. The long-term work of Meech on distant comets and short-period (SP) comets has established that SP comets have undergone significant thermal evolution during their residence in the inner solar system. By studying the Centaurs and comparing them to both the SP comets and the trans-Neptunian objects, it may be possible to look at an earlier, more pristine version of the SP comets. Bauer is beginning a comprehensive study of all the Centaur objects for his thesis. He will attempt to fully characterize their physical properties in the optical and near-infrared regions and to make a sensitive search for activity in these objects.

Fernandez and Whiteley began a program to measure polarimetry from near-Earth asteroids. When the objects are at a high phase (Sun-target-Earth) angle, the surface properties of the various taxonomic classes of asteroids show different degrees of polarization. Moreover, the researchers are studying if polarization can be used to differentiate between near-Earth asteroids perturbed from the main asteroid belt and those with a cometary origin.

Jewitt has used the 8K CCD camera built by Luppino to measure the abundance and size distribution of Jovian Trojan asteroids. These objects, which lead and follow Jupiter by 60° in its orbit, turn out to be nearly as numerous as the main-belt asteroids, when measured to the same limiting size. The Trojans appear comparatively rare in ground-based data, however, because of their greater mean distance from the Sun and the resulting faintness. The new measurements of the Trojans clearly demonstrate a break in the size distribution near 30 km. Smaller Trojans are distributed in a way that suggests an origin by collisional shattering. Larger Trojans occupy a very steep distribution that must have another, perhaps primordial, origin. The small Trojans appear to be collisionally produced fragments of the larger objects. There are not enough small Trojans to supply the flux of short-period comets into the inner solar system. Such comets are thought to originate in the Kuiper Belt, but other sources (including the 1:1 resonances of the gas giant planets) could contribute significantly.

Tholen and M. Sykes (Univ. Arizona) are working with members of the 2MASS (Two Micron All Sky Survey) team to identify and extract broadband infrared observations of asteroids and comets that appear in the 2MASS scans of the entire sky. In the first two incremental data releases, several thousand asteroid detections were made, and prediscovery observations of Comets C/1998 K1 (Mueller) and C/1998 M2 (LINEAR) were identified.

Tholen continued to participate in the Small Bodies Node

of the Planetary Data System. He and the Planetary Science Institute in Tucson comprise the asteroid subnode, which collects and prepares asteroid data for archiving.

9.4 Comets

Meech continued her program to search for observable differences in the physical or chemical nature of the periodic comets (old) compared with the (new) Oort comets by studying their brightness as a function of heliocentric distance, r. The scientific objectives of this study are (1) to search for physical differences in the behavior of the dynamically new comets (those entering the solar system from the Oort cloud for the first time) and the periodic comets, and (2) to interpret these differences, if any, in terms of their physical, chemical nature and the evolutionary histories of the two groups of comets.

Observations of approximately 50 comets over a range of r are complete. The data will be compared to models of the level of activity (brightness and extent of coma) as a function of distance to interpret the observations in terms of possible evolutionary or aging processes, or as differences in primordial source regions. The analysis will involve using Finson-Probstein dust dynamical models to ascertain the onset and cessation of dust production, the grain properties, ejection velocities, and particle size distributions.

Observations of cometary comae at large heliocentric distances are now routine for the dynamically new comets, and this clearly indicates that there is a strong difference in the brightness curves of the Oort comets compared to the periodic comets. While the dynamically new comets and the short-period comets are believed to have formed in different regions, with the SP comets forming at lower temperatures, the differences in activity levels seen between the comet classes are almost certainly due to evolutionary or aging effects.

In collaboration with others, Bauer and Meech used the UH8K Mosaic Camera on the UH 2.2 m telescope to provide ground-based wide-field imaging of the breakup of comet Linear S4 while the comet was being observed by the *Chandra* and *HST* observatories. They monitored the comet's dust production and the rate of dispersion of the cometary debris. Fernandez, with collaborators C. M. Lisse (STScI) and S. B. Peschke (ESA), has been studying the prebreakup dust and nucleus environment of Comet C/1999 S4. By imaging the comet from 0.6 to 20 μm, they are investigating the dust-size distribution, mass-loss rate, silicate-vs.-carbonaceous composition, coma morphology, and the nuclear size and albedo to determine the comet's state in the time leading up to its spectacular disintegration around perihelion.

Fernandez and Meech are investigating the rotation state of the suspected extinct comet and Geminid meteor parent (3200) Phaethon. Using a baseline of photometry covering several years and a large fraction of Phaethon's orbital anomaly, they are disentangling the object's rotational brightness variation as a function of aspect to constrain the shape and spin axis direction. Simultaneous optical and mid-infrared (thermal emission) observations of Phaethon are also being studied to map any albedo variations on the asteroid's surface.

Fernandez has used thermal imaging cameras on IRTF and Keck to measure heat from various small solar system bodies. These measurements constrain the surface properties, especially albedo, and provide a measure of absolute size. He finds that the primitive bodies—nuclei of comets and some dynamically related objects that may be dead or dormant comets—tend to have very low albedos (a few percent) consistent with carbonized surface compositions.

9.5 Outer Solar System Objects

Jewitt continued to explore the Kuiper Belt. A primary activity has been the use of the wide-field CFHT 12K CCD camera for an ecliptic survey designed to measure the size distribution, radial distribution, and inclination distribution of Kuiper Belt objects (KBOs). This survey has revealed about 100 KBOs. The main results include a power-law size distribution with index near -3.8, an inclination distribution about 20° half width at half-maximum, and confirmation of the existence of an outer edge to the classical Kuiper Belt near 50 AU. This work, conducted with Trujillo and J. Luu (Univ. Leiden), defines the current state-of-the-art for studies of the structure of the outer solar system. Of the 350 KBOs known (as of October 2000), about two-thirds have been discovered from Mauna Kea. A continuing effort to obtain follow-up astrometry of these objects has been mounted at the UH 2.2 m telescope.

Sheppard, along with Jewitt, Trujillo, and Australian colleagues, used a modified Baker-Nunn satellite camera in Australia to survey 1400 square degrees in search of bright KBOs and Centaurs. While detecting no new objects, this survey places interesting constraints on the number of such objects that await discovery.

Tholen and J. Davies (JAC) obtained $V - J$ colors for a sample of trans-Neptunian objects via simultaneous observations using the 2.2 m telescope and UKIRT. The bimodal distribution of colors seen by other researchers at visible wavelengths is not apparent in this sample, though there is the possibility of a correlation between color and size (as indicated by the absolute magnitude of the object).

9.6 Planetary Satellites

Tholen continued the reduction and analysis of the Galilean and Saturnian satellite mutual events that occurred in 1997 and 1995, respectively. The events involving Io will be used to make a more precise determination of the satellite's secular acceleration, which can be compared to the amount expected from heat flow measurements. The Saturnian satellite events will be used to improve their ephemerides in support of the *Cassini* spacecraft mission.

9.7 Spacecraft

Meech is a co-investigator on the recently selected Discovery mission *Deep Impact*. This mission will be the first to characterize the interior of a comet by sending a 0.5 ton impactor to excavate a crater on the surface of comet 9P/Tempel 1. Participating scientists will watch the development of the crater, study the surface of the nucleus and the ejecta, and look for changes in the activity of the comet as induced by the impact. The mission will launch during January 2004 for an encounter on 4 July 2005. In preparation for the mis-

sion, Meech is coordinating all of the ground-based observing support. The goals are to fully characterize the nucleus of the comet prior to encounter: its size, albedo, rotation state, and activity level as a function of heliocentric distance. In addition there will be a large-scale multiwavelength Earth and space-based observing program simultaneous with the encounter. Meech and Pittichova have undertaken an extensive international observing campaign using the facilities on Mauna Kea, at Lowell Observatory, at La Palma, and in Chile to attempt to characterize the rotational state of the comet. Results from 1999 indicate that the comet may be in a complex state of rotation, with a period >4 days. Simultaneous optical/IR data were obtained in August to determine the size of the nucleus and albedo.

Pittichova has been working with Meech to analyze comet nucleus and dust data for the targets of the *Stardust*, *Comet Nucleus Tour* (*CONTOUR*), *Deep Space 1* (*DS1*), *Rosetta*, and *Comet Nucleus Sample Return* missions. The goal of the project is to extract as much nucleus information from the database as possible (e.g., nucleus size limits, rotation rate) and to begin modeling the dust activity.

Tholen participated in two meetings of the *MUSES-C* Joint Science Team in Japan. *MUSES-C* is a sample return mission to a near-Earth asteroid. Unfortunately, the failure of the booster during the *ASTRO-E* launch has forced a delay in the *MUSES-C* project, as well as a change in target. The new target is 1998 SF36, which offers an even lower δ-V than the previous target. Tholen and Whiteley successfully recovered this object at the end of September.

The ultimate test of the importance of comets in delivering volatiles to the inner planets will come from an in situ analysis of noble gases and isotopes in the comets themselves. To this end, Owen participated in the planning for the encounter of *DS1* with comet Borrelly, the *CONTOUR* mission, and the development of the Odyssey Discovery Proposal.

10 Solar Physics

The IfA Solar Group consisted of Kuhn, LaBonte, Li, Lin, Mickey, and postdoctoral fellow Kupke. For information about their work, see their Web site (http:// www.solar.ifa .hawaii.edu/). For information about Mees Solar Observatory, see Sec. 4.1 of this report. For information about Solar-C, see Sec. 4.6.

11 Theory

Barnes developed an improved algorithm to classify orbits in two-dimensional potentials. The algorithm reduces a numerically computed orbit to a sequence of sign-changes in x and y; this sequence is then matched against a set of patterns to identify the orbit's family. Previously, the set of patterns was generated by hand; new is the realization that these patterns can be generated from Lissajous figures.

Barnes used an N-body/SPH code to study dissipative galaxy mergers. These calculations included both equal-mass and unequal-mass mergers, significantly increasing the coverage of parameter space. Longer runs than attempted before allowed the formation of gas disks in merger remnants; in most cases these disks are strongly warped. Counterrotating disks arose in about 25% of equal-mass mergers, while none were detected in a comparable sample of unequal-mass mergers.

Barnes studied encounters of simplified stellar models. This study compared the physics of encounters between gas polytropes with the physics of encounters between equivalent collisionless polytropes; the former involve hydrodynamics as well as gravity, while the latter involve gravity alone. While many details of the encounters differ, underlying regularities suggest that analogues between stellar dynamics and hydrodynamics have some validity even in systems far from equilibrium.

Barnes continued to develop SPH techniques for modeling gas in galaxies. Since starburst galaxies are optically thick, it may be appropriate to treat radiative transfer as a diffusive process. This was implemented in an SPH code and shown to work in several simple test cases. However, incorporating this process into a simulation of galactic starbursts is computationally demanding.

Barnes presented invited review talks at "Gas and Galaxy Evolution," Socorro, New Mexico, at "Stellar Collisions, Mergers, and Their Consequences," New York, New York, and at the Fourth Scientific Meeting of the Spanish Astronomical Society, Santiago de Compostela, Spain.

Kaiser, Tonry, and Luppino explored a new technique for providing adaptive optics image compensation for wide-field imaging. Deep optical imaging surveys are limited by solid angle, depth, and atmospheric seeing, which limits the angular resolution. Conventional adaptive optics provides spectacular image quality, but only over a limited field of view around the guide star, since widely separated objects probe independent paths through the atmosphere. The new technique allows more modest image compensation, roughly a factor of 3 in image size, but over a wide field of view. The strategy is to use an array of small telescopes with image tracking to take out the atmospheric jiggling of the images. Novel features of the approach are the use of an electronic "rubber focal plane" that allows one to track the image motions at all points in the field, and the combination of guide star motion data from the array of telescopes that is needed to make this work. A detailed theoretical analysis of the performance of such an imaging system was performed. Exact analytic results for the fast-guiding point-spread function were obtained, including the effects of isoplanatism. Detailed simulations were carried out to assess the required sampling rate and guide star densities. Careful consideration was given to the effects of multiple turbulent layers and to the persistence of the turbulence. This approach would allow one to construct a system with a large collecting area and a degree-scale field of view, but with images about a factor of 3 sharper than with conventional designs.

Kaiser worked with Donovan to make calculations of the limiting sensitivity for weak lensing observations. The Hubble Deep Field images were processed to simulate images like those obtainable on ground-based telescopes. Atmospheric seeing and other effects were accurately modeled, as were the effects of image processing. State-of-the-art shear measurement algorithms were used to quantify the limiting sensitivity as a function of seeing and depth of the observations.

12 Public Outreach: The TOPS Program

The Toward Other Planetary Systems (TOPS) program is a five-year summer teacher enhancement workshop (currently in its second year) for high school science and math teachers and students in Hawaii and the Pacific. TOPS allows them to learn about math, science, and technology through their natural curiosity about astronomy. Developed by Meech and collaborators, the workshops are supported by funds from the NSF, NASA, and local private donors. The program goals are

- To give science and math teachers content material and experience in astronomy.
- To expose teachers to and train them in the use of exemplary hands-on classroom activities.
- To train teachers in proper evaluation of students.
- To give teachers and students critical thinking skills.
- To expose students to science careers.
- To provide a pathway for students to have outstanding research-related opportunities in higher education.

During the summer 2000 workshop, held from June 13–30, 27 teachers and 22 high school students from Hawaii and U.S.-affiliated Pacific regions engaged in hands-on activities, developed their computer skills, listened to lectures, participated in discussion groups, saw demonstrations, and toured observatories. At night, they undertook research projects with small telescopes.

The program also incorporates an archaeoastronomical component, with fieldwork that ties in modern and ancient cultural astronomical practices with hands-on technology. In addition, the teachers are trained in assessment and educational pedagogy, and are supported with pre- and post-workshop activities. There will also be secondary workshops for the school complexes (elementary and middle schools affiliated with a high school) scheduled throughout fall 2000 and spring 2001. For more information, see http://www.ifa.hawaii.edu/tops

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